# Cost and Performance Summary Report
# Mulch Biowall at Altus Air Force Base, Landfill 3, Oklahoma

**Summary Information [1]**

Landfill (LF)-4, located in the northeastern portion of Altus AFB, operated from 1956 through 1983. LF-4 includes several disposal features, including LF-3 and a Petroleum, Oil, and Lubricant (POL) Tank Sludge Burial area. LF-3 is located at the eastern portion of the site, and is bordered by the Ozark lateral irrigation canal on the west and south, Stinking Creek on the northeast, an unnamed drainage canal on the north, and the Base boundary and Taxiway "M" on the east. From 1956 to 1965, the LF-3 portion of LF-4 received waste materials including garbage, wood, paper, metal, and shop wastes. After 1965, LF-3 received construction debris, concrete, brush, and several drums of paint waste. Waste at LF-3 was buried in trenches at depths ranging from 6 to 8 feet below ground surface (bgs). Historical waste management activities at LF-3 have resulted in low concentrations of chlorinated solvents in groundwater beneath, and immediately to the east-southeast of the landfill.

Trichloroethene (TCE) and cis-dichloroethene (cDCE) are the most prevalent chlorinated solvents in both extent and concentration in groundwater at LF-3. Figure 1 shows the approximate location of LF-3 and the aerial extent of the TCE plume based on groundwater data collected in April 1999. The TCE plume originates from LF-3 and extends southeastward approximately 4,000 feet to the Base's eastern boundary. Concentrations of TCE in April 1999 ranged up to 6,110 micrograms per liter (μg/L). Migration of the TCE plume to the east appears to be limited by Stinking Creek. Groundwater samples collected from monitoring locations northeast of Stinking Creek during previous investigations did not contain detectable levels of TCE or other CAHs. Stinking Creek may be exerting hydraulic control, resulting in no further TCE plume migration northeast of the creek. Hydraulic control could occur under both gaining- and losing-stream scenarios and could vary seasonally. Under a losing-stream scenario, groundwater recharge could create a barrier to flow in the form of a groundwater divide. Under a gaining-stream scenario, a significant percentage of under-flow could be captured by the creek.

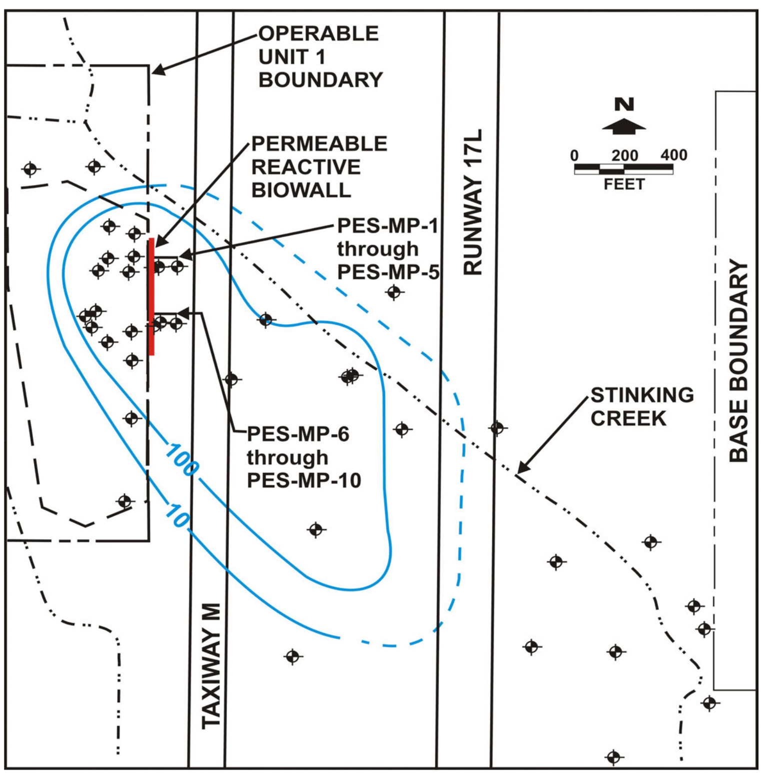


**Figure 1. Location of Biowall relative to TCE Plume (isoconcentration contours in micrograms per liter of TCE, April 1999) [1]**

**Timeline [1]**

| Date(s) | Activity |
|---|---|
| June 19 – 23, 2002 | Mulch biowall installed |
| July 16 – 19, 2002 | Monitoring wells installed |
| July and September 2002<br>March 2003 | Groundwater sampling performed |

**Factors That Affected Technology Cost or Performance - Matrix Characteristics [1]**

Listed below are the key matrix characteristics for this technology and the values measured for each during site characterization.

Surface soils at the site consist of approximately 5 feet of clayey silt and weathered and fractured stiff silty clay that extends to depth of approximately 25 to 30 feet bgs. These sediments are underlain by well-cemented silt and dense shale of the Hennessey Group of Permian age. Shallow groundwater occurs under unconfined conditions and generally flows towards the east-southeast and Stinking Creek. Shallow groundwater at the site occurs at a seasonally variable depth of approximately 6 to 12 feet bgs. The groundwater surface slopes toward the southeast, with an average horizontal hydraulic gradient of approximately 0.003 foot per foot (ft/ft). Hydraulic conductivity ranges from 8.4 to 20 feet per day (ft/day) in the overburden clay. Using a calculated hydraulic conductivity of 8.4 to 20 ft/day, a horizontal hydraulic gradient of 0.003 ft/ft, and an estimated effective porosity of 5 percent, the adjective groundwater flow velocity in the overburden clay is calculated to range from 0.50 to 1.2 ft/day [183 to 438 feet per year (ft/yr)]. Visual examination of sediments from borehole cores indicates the presence of secondary permeability due to dissolution features and soil fractures.

| Parameter | Value |
|---|---|
| Soil Classification: | Clayey silt and weathered and fractured stiff silty clay |
| Hydraulic Conductivity: | 8.4 to 20 ft/day |
| Hydraulic Gradient: | 0.003 ft/ft |
| Porosity: | 5% - estimated effective porosity |
| Depth to Groundwater: | 6 – 12 ft |

**Treatment Technology Description [1]**

A mulch biowall was constructed across the path of groundwater flow on the downgradient edge (eastern boundary) of LF-3, as shown in Figure 1. The biowall was intended to capture over 80 percent of the contaminant mass flux originating from the landfill. The biowall was 455 foot-long, 24 foot-deep, and 1.5 foot-wide, and was installed from June 19 to 23, 2002 by DeWind Environmental of Zeeland, Michigan. The biowall consisted of approximately 300 cubic yards of shredded mulch, 60 cubic yards of cotton gin compost, and 265 cubic yards of sand. The mulch consisted of shredded plant material generated by the City of Altus after a winter storm event and during seasonal landscaping operations throughout the surrounding community.

This treatment method relies on the flow of groundwater under a natural hydraulic gradient through the biowall to promote contact with slowly-soluble organic matter. Degradation of the substrate by microbial processes in the subsurface provides a number of breakdown products, including metabolic and humic acids. The breakdown products and metabolic acids produced by degradation of mulch in a saturated subsurface environment provide secondary electron donors or fermentable substrates for hydrogen generation, the primary electron donor used in reductive dechlorination.

A continuous trenching machine was used to excavate the trench for the biowall and simultaneously place the mulch, compost, and sand mixture into the trench. The trencher is a track-mounted vehicle that has a cutting boom resembling a large chain saw (i.e., linked chain belt with cutting teeth). A steel box with a hopper assembly is fitted atop the cutting boom. The cutting boom excavates a trench by simultaneously rotating the cutting chain and advancing the boom until the desired depth of excavation relative to the ground surface has been achieved. The steel box and hopper assembly provide for stabilization of the trench sidewalls during excavation and subsequent placement of the sand and mulch mixture, which is introduced through the feed hopper. Simultaneous excavation and placement of backfill materials eliminated the concerns associated with open excavations. Soil generated during excavation of the biowall was graded on top of the installed biowall. The location and extent of the biowall was marked with metal fence posts painted a high visibility color.

Following construction of the biowall, ten groundwater monitoring wells and four soil vapor monitoring points were installed. Groundwater monitoring wells were installed along two lines perpendicular to the biowall. Wells were installed within the footprint of the biowall, and at distances of 5, 10, 30, and 100 feet downgradient (to the east) of the biowall. These points are used to monitor groundwater geochemical indicators and contaminant concentrations within and immediately downgradient of the biowall. Two existing groundwater monitoring wells (OU-1-01 and WL019) located approximately 25 to 30 feet upgradient of the biowall are also being monitored. Two soil vapor monitoring points were installed within the footprint of the biowall, and two vapor points were installed at a distance of 5 feet downgradient of the biowall. These points are used to monitor volatilization or accumulation of vapors in the vadose zone that may be indicative of the biochemical processes within and immediately downgradient of the biowall.

**Performance Information [1]**

The objective for this project was to assess the applicability and feasibility of promoting *in situ* bioremediation of TCE and cDCE in groundwater, and to contain and attenuate a shallow groundwater plume to prevent surface water discharge or off-base migration.

Groundwater samples were collected after installation of the biowall and were analyzed for chlorinated solvents and their degradation products, dissolved oxygen (DO), nitrate, ferrous iron, manganese, sulfate, hydrogen sulfide, carbon dioxide, methane, ethane, ethane, oxidation-reduction potential (ORP), alkalinity, pH, temperature, specific conductance, total organic carbon (TOC), volatile fatty acids (VFAs), and chloride.

Table 1 summarizes analytical results for chlorinated solvents detected in groundwater during monitoring in July 2002, September 2002, and March 2003. Well installation and the first round of groundwater sampling was performed approximately 4 weeks after installation of the biowall, based in part on availability of the drilling contractor. While true “baseline” conditions for the wells located in the trench (PES-MP01 and PES-MP06) were not obtained, data from upgradient wells were used to infer “baseline” conditions at the site.

The primary contaminants detected at the site include TCE and cDCE. Concentrations of TCE ranged up to 8,000 μg/L at upgradient location OU-1-01 in September 2002, and concentrations of cDCE ranged up to 1,300 μg/L at upgradient location OU-1-01 in March 2003. Lesser concentrations (less than 25 μg/L) of tetrachloroethene (PCE), *trans*-1,2-DCE, 1,1-DCE, and vinyl chloride (VC) also were detected at the site. During the 4 week sampling event in July 2002, the ratio of TCE to cDCE ranged from 25:1 to 1.5:1, with the notable exception of biowall location PES-MP01. For location PES-MP01, the ratio of TCE to cDCE was less than 0.1:1, indicating that degradation of TCE to cDCE was stimulated within the biowall within 4 weeks of installation. As of the 3 month monitoring event, the trend of decreasing TCE and increasing cDCE was observed at all locations located within 30 feet downgradient of the biowall. Furthermore, in March 2003 concentrations of TCE have been lowered to less than 5 μg/L at four locations (PES-MP01, PES-MP06, PES-MP07, and PES-MP08).

The average decrease in TCE concentrations from July 2002 to March 2003 within the biowall was 98.7 percent. For all locations downgradient of the biowall, the average decrease in TCE was 64.5 percent over the same time period.

Concentrations of cDCE generally increased from July 2002 to September 2002 within and downgradient of the biowall, with the exception of PES-MP01 where the concentration of cDCE decreased. From September 2002 to March 2003, concentrations of cDCE decreased at five locations (PES-MP01, PES-MP02, PES-MP03, PES-MP07 and PES-MP08). Concentrations of cDCE were relatively stable (increased 100 μg/L or less) at other locations within or downgradient of the biowall, with the lone exception of PES-MP05. These data suggest that degradation of cDCE is occurring in the biowall system, without an accumulation of VC.

A more important observation is that the total molar concentration of chlorinated ethenes for the biowall locations in March 2003 was 91.9 percent less than that measured in the upgradient locations. Therefore, the apparent accumulation of cDCE should be taken in the context of a significant reduction in overall contaminant mass.

Table 2 provides analytical results for selected geochemical parameters. Comparison of geochemical parameters for biowall locations PES-MP01 and PES-MP06 to locations outside the biowall can be summarized as follows:

- With the exception of the furthest downgradient well locations, dissolved oxygen levels were already depleted (less than 2 milligrams per liter [mg/L]) in the study area.
- Oxidation-reduction potential in the biowall has been lowered to –218 millivolts (mV) at PES-MP01 and –342 mV at PES-MP06 as measured in March 2003.
- Sulfate levels in the biowall have been depleted to 16 to 350 mg/L in March 2003, compared to upgradient background levels of 1,600 mg/L to 2,000 mg/L. Meanwhile, hydrogen sulfide levels are elevated in the biowall at concentrations of 3.5 mg/L (PES-MP01) and 94 mg/L (PES-MP06).

**TABLE 1**
**CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER**

| Sample Identification | Sampling Location | Sample Date | PCE[a] (µg/L)[b] | TCE[a] (µg/L) | 1,1-DCE[a] (µg/L) | *cis*-1,2-DCE (µg/L) | *trans*-1,2-DCE (µg/L) | VC[a] (µg/L) | 1,1-DCA[a] (µg/L) | Chloroform (µg/L) | Chloromethane (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Upgradient Monitoring Wells** | | | | | | | | | | | |
| OU-1-01 | Upgradient of MP01 | 19-Jul-02 | <9.3 | 6,200 | 2.5J[c] | 850 | 9.8 | <7.3 | <2.7 | 1.0J | <8.7 |
| | | 18-Sep-02 | <31 | 8,000 | 4.1J | 1,100 | 13.0 | <24 | <8.9 | <8.9 | <29 |
| | | 20-Mar-03 | <7.0 | 7,200 | 3.4J | 1,300 | 13.0 | 0.27J | <2.0 | 1.1J | <6.5 |
| WL019 | Upgradient of MP06 | 19-Jul-02 | 0.28J | 1,500 | 0.74J | 130 | 3.0 | <4.4 | <1.6 | 1.1J | <5.2 |
| | | 19-Sep-02 | 0.19J | 1,200 | 0.82J | 140 | 7.6 | <3.7 | <1.3 | 0.81J | <4.3 |
| | | 19-Mar-03 | 0.23J | 1,300 | 0.60J | 130 | 2.6 | 0.076J | <0.40 | 0.92 | <1.3 |
| **Monitoring Points** | | | | | | | | | | | |
| PES-MP01 (0') | Within Biowall | 18-Jul-02 | <5.6 | 48 | <4.8 | 680 | 1.8J | <4.4 | <1.6 | <1.6 | <5.2 |
| | | 18-Sep-02 | <2.8 | 0.12J | <2.4 | 480 | 0.76J | 2.5 | <0.80 | <0.80 | <2.6 |
| | | 20-Mar-03 | <1.4 | 0.70J | <1.2 | 250 | 0.44J | 2.0 | <0.40 | <0.40 | <1.3 |
| PES-MP02 (5') | 5' Downgradient of MP01 | 18-Jul-02 | 0.10J | 290 | <1.2 | 49 | 0.6 | <1.1 | <0.40 | 0.079J | <1.3 |
| | | 18-Sep-02 | <3.5 | 55 | 1.4J | 770 | 3.6 | 0.64J | <1.0 | <1.0 | <3.2 |
| | | 20-Mar-03 | 0.087J | 170 | 1.1J | 610 | 5.6 | 0.75J | <0.40 | <0.40 | <1.3 |
| PES-MP03 (10') | 10' Downgradient of MP01 | 18-Jul-02 | 0.18J | 350 | <1.2 | 22 | 0.39J | <1.1 | <0.40 | 0.18J | <1.3 |
| | | 18-Sep-02 | <5.6 | 150 | 3.7J | 1,200 | 8.5 | 0.27J | <1.6 | 0.59J | <5.2 |
| | | 20-Mar-03 | <2.8 | 160 | 1.3J | 510 | 4.4 | 0.38J | <0.80 | <0.80 | <2.6 |
| PES-MP04 (30') | 30' Downgradient of MP01 | 18-Jul-02 | 0.20J | 430 | <1.2 | 260 | 2.1 | 0.055J | <0.40 | 0.13J | 0.42J |
| | | 18-Sep-02 | <5.6 | 120 | 3.0J | 1,100 | 8.8 | 0.35J | <1.6 | <1.6 | <5.2 |
| | | 20-Mar-03 | <7.0 | 130 | 2.4J | 1,200 | 15 | 1.2J | <2.0 | <2.0 | <6.5 |
| PES-MP05 (100') | 100' Downgradient of MP01 | 18-Jul-02 | 0.37J | 2,500 | 1.1J | 240 | 15 | <5.5 | <2.0 | 0.86J | <6.5 |
| | | 19-Sep-02 | <16 | 3,000 | 2.5J | 590 | 25 | <12 | <4.4 | 0.92J | <14 |
| | | 19-Mar-03 | 0.28J | 2,000 | 3.7 | 1,500 | 31 | 0.60J | <0.40 | 1 | <1.3 |
| PES-MP06 (0') | Within Biowall | 18-Jul-02 | <2.8 | 170 | <2.4 | 80 | 2.8 | <2.2 | <0.80 | <0.80 | <2.6 |
| | | 17-Sep-02 | <2.8 | 5.2 | <2.4 | 310 | 2.7 | 1.5J | <0.80 | <0.80 | <2.6 |
| | | 18-Mar-03 | <1.4 | 2.0 | 0.12J | 360 | 7.6 | <1.1 | <0.40 | <0.40 | <1.3 |
| PES-MP07 (5') | 5' Downgradient of MP06 | 19-Jul-02 | 0.051J | 190 | <1.2 | 130 | 6.3 | <1.1 | <0.40 | <0.40 | <1.3 |
| | | 17-Sep-02 | <2.8 | 10 | <2.4 | 300 | 4.6 | 0.88J | <1.2 | <0.80 | <2.6 |
| | | 18-Mar-03 | <1.4 | 2.6 | 0.42J | 290 | 16 | 2.6 | <0.40 | <0.40 | <1.3 |
| PES-MP08 (10') | 10' Downgradient of MP06 | 19-Jul-02 | 0.063J | 250 | <1.2 | 130 | 7 | 0.16J | <0.40 | 0.059J | <1.3 |
| | | 19-Sep-02 | <1.4 | 4.5 | 0.58J | 330 | 5.5 | 0.90J | <0.40 | <0.40 | <1.3 |
| | | 18-Mar-03 | <1.4 | 4.6 | 0.55J | 320 | 14 | 2.2 | <0.40 | <0.40 | <1.3 |
| PES-MP09 (30') | 30' Downgradient of MP06 | 17-Jul-02 | <1.4 | 220 | 0.56J | 150 | 9.9 | 0.19J | <0.40 | 0.081J | <1.3 |
| | | 19-Sep-02 | <1.4 | 69 | 0.69J | 200 | 17 | 0.38J | <0.40 | <0.40 | <1.3 |
| | | 19-Mar-03 | <1.4 | 17 | 0.49J | 200 | 24 | 1.6 | <0.40 | <0.40 | <1.3 |
| PES-MP10 (100') | 100' Downgradient of MP06 | 19-Jul-02 | 0.47J | 670 | 0.49J | 27 | 2.4 | <2.2 | 0.19J | 0.66J | <2.6 |
| | | 19-Sep-02 | 0.28J | 460 | 0.50J | 32 | 4.7 | <2.2 | 0.17J | 0.52J | 2.6 |
| | | 19-Mar-03 | 0.28J | 390 | 0.53J | 42 | 21 | 0.13J | 0.18J | 0.43 | <1.3 |

[a] PCE = tetrachloroethene, TCE = trichloroethene, DCE = dichloroethene, VC = vinyl chloride, DCA = dichloroethane
[b] µg/L = micrograms per liter.
[c] J-flag indicates the concentration is estimated.

**TABLE 2**
**GROUNDWATER GEOCHEMICAL DATA**

| Sample Location (feet from trench) | Sample Date | Temp (°C)[a] | pH (su)[b] | Conductivity (mS/cm)[c] | Dissolved Oxygen (mg/L)[d] | Redox Potential (mV)[e] | Total Organic Carbon (mg/L) | Nitrate (mg/L) | Nitrite (mg/L) | Manganese (mg/L) | Ferrous Iron (mg/L) | Sulfate (mg/L) | Hydrogen Sulfide (mg/L) | Chloride (mg/L) | Carbon Dioxide (mg/L) | Alkalinity (mg/L) | Dissolved Hydrogen (nM)[f] | Methane (µg/L)[g] | Ethane (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Upgradient Monitoring Wells** | | | | | | | | | | | | | | | | | | | |
| OU-1-01 | 17-Jul-02 | 18.8 | 6.79 | 4.41 | <0.01 | 88 | <5.0 | <2.5 | <2.5 | 0.04 | <0.01 | 1,600 | <0.01 | 320 | 100 | 380 | NA | 2.4 | 0.022 |
| | 18-Sep-02 | 21.0 | 6.90 | 4.25 | <0.01 | 9 | 5.6 | 0.38 | <0.10 | <0.01 | <0.01 | 1,700 | 0.1 | 290 | 50 | 340 | NA | 5.2 | 0.099 |
| | 20-Mar-03 | 13.6 | 7.03 | 4.58 | 1.93 | 41 | 6.4 | <0.50 | <0.50 | 0.55 | <0.01 | 1,600 | <0.01 | 350 | 25 | 272 | NA | 6.4 | 0.018 |
| WL019 | 17-Jul-02 | 19.3 | 6.90 | 4.81 | <0.01 | 107 | <5.0 | <2.5 | <2.5 | 0.35 | <0.01 | 2,000 | 0.10 | 340 | 60 | 320 | NA | 4.2 | 0.029 |
| | 19-Sep-02 | 19.0 | 6.92 | 4.44 | <0.01 | 150 | <5.0 | 3.4 | <0.10 | 0.21 | <0.01 | 1,600 | 0.04 | 270 | 50 | 400 | NA | 3.6 | 0.042 |
| | 19-Mar-03 | 16.1 | 6.85 | 4.57 | 1.45 | 60 | <5.0 | <0.50 | <0.50 | 0.44 | <0.01 | 2,000 | 0.2 | 270 | 25 | 204 | NA | 26 | 0.014 |
| **Monitoring Points** | | | | | | | | | | | | | | | | | | | |
| PES-MP01 (0') | 18-Jul-02 | 22.9 | 6.75 | 7.94 | 0.09 | -365 | 2,800 | <0.5 | <0.5 | 2.52 | 3.52 | 410 | 15.4 | 390 | 600 | 3,360 | NA | 8,800 | 0.008 |
| | 18-Sep-02 | 19.18 | 7.08 | 7.76 | <0.01 | -212 | 380 | <0.10 | <0.10 | 0.52 | 1.16 | 17 | 10 | 350 | 550 | 3,400 | 2.0 | 7,000 | 0.014 |
| | 20-Mar-03 | 15.4 | 6.82 | 6.47 | 1.67 | -218 | 200 | 2.0 | <0.5 | 0.06 | 2.28 | 16 | 3.5 | 310 | 340 | 1,904 | 2.4 | 8,000 | 0.040 |
| PES-MP02 (5') | 18-Jul-02 | 19.8 | 7.11 | 5.24 | 0.19 | -94 | 19 | 10 | <0.10 | 0.38 | 0.68 | 1,900 | 2.4 | 370 | 80 | 300 | NA | 150 | 0.016 |
| | 18-Sep-02 | 19.4 | 6.82 | 5.13 | <0.1 | -179 | 43 | 2.4 | <0.10 | 1.8 | 2.3 | 1700 | 3.2 | 350 | 200 | 900 | 1.7 | 3,500 | 0.011 |
| | 20-Mar-03 | 16.1 | 6.80 | 4.95 | 1.74 | -158 | 24 | 7.0 | <0.50 | 0.16 | 2.94 | 1700 | 0.6 | 310 | 60 | 306 | 0.60 | 1,800 | 0.008 |
| PES-MP03 (10') | 18-Jul-02 | 20.4 | 7.05 | 5.05 | 1.91 | 20 | 5.2 | 9.5 | <0.10 | 0.70 | 0.16 | 1,900 | <0.01 | 370 | 45 | 260 | NA | 200 | 0.013 |
| | 18-Sep-02 | 22.4 | 6.67 | 4.93 | <0.01 | -68 | 16 | 0.38 | <0.10 | 0.14 | 0.2 | 1,900 | 80.0 | 360 | 40 | -- | NA | 1,400 | <0.005 |
| | 20-Mar-03 | 16.3 | 6.86 | 5.16 | 1.29 | -70 | 15 | <0.50 | <0.50 | 0.17 | 0.4 | 2,000 | 1.0 | 370 | 60 | 340 | NA | 1,900 | <0.005 |
| PES-MP04 (30') | 18-Jul-02 | 23.0 | 6.62 | 5.83 | 0.01 | -204 | 130 | <0.10 | <0.10 | 0.13 | 0.96 | 1,800 | 3.5 | 370 | 100 | 460 | NA | 1,900 | 0.039 |
| | 18-Sep-02 | 18.8 | 6.76 | 4.98 | <0.01 | -169 | 30 | 0.56 | <0.10 | 0.34 | 1.64 | 1,700 | 1.2 | 340 | 120 | 560 | NA | 4,100 | <0.005 |
| PES-MP05 (100') | 18-Jul-02 | 19.5 | 6.93 | 5.27 | 4.55 | 63 | <5.0 | 6.8 | <0.10 | 0.50 | <0.01 | 1,900 | 0.1 | 370 | 65 | 300 | NA | 4.8 | 0.023 |
| | 19-Sep-02 | 18.4 | 7.01 | 4.62 | <0.01 | 26 | 5.4 | 4.0 | <0.10 | <0.01 | <0.01 | 1,800 | 0.2 | 360 | 20 | 200 | NA | 14 | 0.052 |
| | 19-Mar-03 | 16.6 | 6.77 | 4.57 | 1.30 | 42 | 10 | <0.50 | <0.50 | 0.83 | <0.01 | 1,700 | 0.2 | 320 | 40 | 340 | NA | 1,300 | 0.039 |
| PES-MP06 (0') | 18-Jul-02 | 20.5 | 6.43 | 7.16 | <0.01 | -266 | NA[h] | 14 | <0.10 | 0.42 | 4.14 | NR[i] | 39.6 | NR | 480 | 2,400 | NA | 7,900 | 0.064 |
| | 17-Sep-02 | 19.4 | 6.98 | 6.18 | <0.01 | -325 | 390 | 2.5 | <0.10 | 0.27 | 0.3 | 300 | 14.1 | 300 | 120 | 3,720 | 2.2 | 7,900 | 0.064 |
| | 18-Mar-03 | 16.2 | 6.80 | 6.12 | 1.84 | -342 | 140 | <0.50 | <0.50 | 0.09 | 0.12 | 350 | 94.0 | 320 | 300 | 3,400 | 1.3 | 8,500 | 0.008 |
| PES-MP07 (5') | 19-Jul-02 | 20.2 | 6.53 | 5.90 | <0.01 | -227 | 710 | <0.10 | <0.10 | 1.5 | 1.7 | 1,100 | 19.2 | 300 | 300 | 1,200 | NA | 2,500 | 0.100 |
| | 17-Sep-02 | 19.8 | 6.82 | 4.20 | <0.01 | -201 | 80 | <0.10 | <0.10 | 0.5 | 0.9 | 700 | 8.8 | 280 | 90 | 1,680 | 2.0 | 6,400 | 0.024 |
| | 18-Mar-03 | 17.1 | 6.49 | 4.77 | 1.25 | -173 | 110 | <0.50 | <0.50 | 1.05 | 2.67 | 2,600 | 1.9 | 240 | 125 | 1,428 | 0.79 | 7,400 | 0.005 |
| PES-MW8 (10') | 19-Jul-02 | 21.1 | 6.67 | 5.85 | <0.01 | -235 | 520 | <0.10 | <0.10 | 0.78 | 0.75 | 1,400 | 15.6 | 290 | 240 | 960 | NA | 1,700 | 0.300 |
| | 19-Sep-02 | 19.6 | 6.80 | 4.63 | <0.01 | -237 | 77 | 1.9 | <0.10 | 0.15 | 1.08 | 800 | 19.0 | 300 | 200 | 1,400 | NA | 6,200 | 0.030 |
| | 18-Mar-03 | 17.0 | 6.36 | 5.05 | 1.11 | -179 | 100 | <0.50 | <0.50 | 0.24 | 2.29 | 1,000 | 6.3 | 370 | 150 | 1,190 | NA | 6,900 | 0.008 |
| PES-MP09 (30') | 17-Jul-02 | 21.2 | 7.03 | 4.39 | 0.21 | -6 | 17 | <0.10 | <0.10 | 0.06 | 1.33 | 1,800 | 1.6 | 250 | 115 | 220 | NA | 47 | 0.069 |
| | 19-Sep-02 | 19.4 | 7.01 | 3.82 | <0.01 | -161 | 25 | <0.10 | <0.10 | 0.02 | 0.9 | 1,100 | <0.01 | 240 | 100 | 400 | NA | 3,300 | 0.065 |
| | 19-Mar-03 | 16.4 | 6.55 | 4.16 | 1.34 | -8 | 43 | 2.8 | <0.50 | 0.33 | 0.14 | 860 | <0.01 | 230 | 90 | 952 | NA | 7,600 | 0.015 |
| PES-MW10 (100') | 19-Jul-02 | 19.5 | 7.15 | 5.85 | 8.3[j] | 45 | <5.0 | <0.10 | <0.10 | 0.10 | <0.01 | 2,200 | 0.9 | 380 | 40 | 120 | NA | 5.2 | 0.110 |
| | 19-Sep-02 | 18.8 | 7.22 | 5.10 | 4.18 | 72 | <5.0 | 6.1 | <0.10 | 0.2 | 0.03 | 2,100 | 0.6 | 340 | 25 | 220 | NA | 0.990 | 0.068 |
| | 19-Mar-03 | 16.3 | 6.93 | 5.17 | 3.37 | 70 | <5.0 | 6.8 | <0.50 | 0.28 | 0.08 | 2,500 | <0.01 | 320 | 30 | 204 | NA | 24 | 0.120 |

a/ °C = degrees Centigrade.
b/ su = standard pH units.
c/ mS/cm = millisiemens per centimeter.
d/ mg/L = milligrams per liter.
e/ mV = millivolts.
f/ nM = nanomoles.
g/ µg/L = micrograms per liter.
h/ NA = not analyzed.
i/ NR = not reported, results were out of control limits due to sample concentration.
j/ Dissolved oxygen data collected at this location may not be reprensentative of stable conditions because the well was purged dry.

- Background concentrations of methane have been measured at less than 0.01 mg/L. Methane levels in the biowall are elevated at concentrations of 8.0 (PES-MP01) and 8.5 mg/L (PES-MP06) in March 2003.
- TOC (unfiltered samples) within the biowall was measured at 2,800 mg/L for location PES-MP01 in July 2002 (4 weeks after installation), but dropped to concentrations of 200 mg/L (PES-MP01) and 140 mg/L (PES-MP06) in March 2003 (9 months after installation). Elevated levels of TOC (greater than 20 mg/L) were observed as far downgradient as wells PES-MP04 and PES-MP09, located 30 feet from the biowall.
- Total metabolic acids (comprised primarily of acetic, propionic, and butyric acids) are elevated in the biowall, but have shown a decreasing trend similar to TOC.

## Cost Information

Cost information is summarized below. Capital cost to procure materials and install the biowall was $165,000, or approximately $360 per linear foot. Of this cost, $115,000 was for the trenching subcontractor ($250 per linear foot). Capital cost also included grinding and transporting the mulch to the Base, installation of the monitoring system, and surveying.

Monitoring cost are approximately $17,000 per event. Future cost of operations and maintenance (O&M) is estimated to be $42,000, consisting of biannual monitoring, reporting, and project management.

| Item | Cost |
|---:|---:|
| System Design and Work Plan: | $12,000 |
| System Installation: | $165,000 |
| Process Monitoring (3 events): | $51,000 |
| Reporting, Meetings, and Administration: | $37,000 |
| **Total Cost:** | **$265,000** |
| **Future Annual O&M** | **$42,000** |

## Observations and Lessons Learned [1]

Geochemical data indicate that levels of organic carbon within the biowall were sufficient to induce sulfate reduction and methanogenesis, oxidation-reduction conditions that are highly conducive to reductive dechlorination of chlorinated compounds. Elevated levels of TOC and metabolic acids (primarily acetic, propionic, and butyric) were observed. Fermentation of these low-molecular weight fatty acids is known to produce molecular hydrogen and to stimulate reductive dechlorination. An average decrease of 98 percent in concentrations of TCE were observed within the biowall at 3 and 9 months following installation, with concentrations of TCE less than 5 µg/L at four locations in March 2003.

Concentrations of cDCE declined at five locations within or downgradient of the biowall over the period from September 2002 to March 2003, indicating that degradation of cDCE is occurring and that in many cases the rate of degradation of cDCE exceeds the rate of transformation of TCE to cDCE. Furthermore, a 92 percent differential in total molar concentration of chlorinated ethenes was observed between the upgradient and biowall monitoring locations in March 2003.

The next scheduled sampling event will be conducted in September 2003, approximately 15 months after biowall installation.

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## References

1. Bruce Henry, Parsons. 2003. Draft Technical Memorandum, Draft Interim Monitoring Results for a Mulch Biowall at Site LF-3 (OU 1), Altus AFB, Oklahoma. To Art Whallon, Altus AFB, and Jim Gonzales, AFCEE. May 20.